Detection of H_3^+ in the interstellar medium of IRAS 08572+3915

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Abstract.

The first detection of the molecular ion H_3^+ in an extragalactic object has been made toward the highly obscured ultraluminous galaxy IRAS 08572+3915. Two absorption features in its spectrum near 3.9 μm are identified as the redshifted 3.668 μm H_3^+ doublet and 3.716 μm singlet lines of H_3^+ , both previously detected in a number of galactic dark and diffuse clouds. We discuss the probable location of the H_3^+ in this galaxy.

1 Introduction

H₃⁺, the highly reactive molecular ion upon which interstellar gas phase chemistry is based [6, 12], is important observationally for understanding dark and diffuse interstellar clouds [5]. In both types of clouds it is produced following cosmic ray ionization of H_2 to H_2^+ , which quickly reacts with H_2 to form H_3^+ . H₃⁺ is destroyed readily in dark clouds by reactions with neutral molecules (principally by CO) and atoms (mainly by O) and even more readily in diffuse clouds by dissociative recombination on electrons, which, due to the ionization of carbon, are much more abundant than in dark clouds. The absorption strengths of H₃⁺ lines provide basic information on the cloud dimensions and environment, in addition to temperature. Assuming a value for the ionization rate, the column density of H₃⁺ directly yields either the distance through the cloud to an embedded continuum source or the thickness of an intervening cloud or group of clouds. Alternatively, if an estimate for the line of sight distance through the absorbing material is available, the ionization rate can be determined from the column density. These inferences are possible because unlike most other molecules, the number density of H_3^+ is a constant that depends only on whether a cloud is dark or diffuse. This unusual property of H₁⁺ comes about because its creation rate per unit volume is proportional to the first power of the cloud density, rather than the square.

 ${\rm H_3^+}$ has been detected in both dark and diffuse clouds by virtue of its vibration-rotation transitions near 3.7 $\mu{\rm m}$ (an ortho-para doublet at 3.668 $\mu{\rm m}$ and a para singlet at 3.715 $\mu{\rm m}$). The amounts of ${\rm H_3^+}$ that have been found in dark clouds are consistent with predictions based on the estimated production rate and measured destruction rates [3, 9]. In diffuse clouds, however, there is a large difference between the observed and predicted column densities [4, 10]; the cause may be the use of an inaccurate value for the rate of dissociative recombination on electrons.

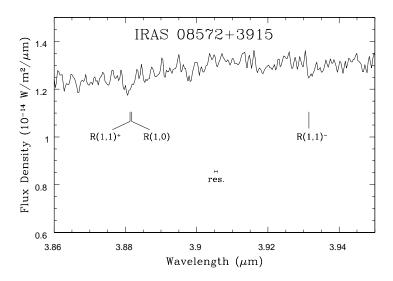


Figure 1: The spectrum of IRAS 08572+3915 from 3.86 to 3.95 μ m, at R $\sim 5,000$ The predicted wavelengths of H_3^+ lines (using z=0.05821; Solomon et al. 1997) are indicated.

The detection of strong $\rm H_3^+$ absorption toward the center of the Galaxy [4] suggests that it is possible to detect $\rm H_3^+$ in the interstellar medium of suitable external galaxies - those with sufficiently bright and compact sources of infrared continuum radiation as well as long columns of interstellar molecular gas along their lines of sight. Although 8–10 m telescopes and their successors will be required for studying $\rm H_3^+$ in all but a very few of the most brightest candidates, at the United Kingdom 3.8 m Infrared Telescope (UKIRT) a search was initiated in one of the most promising galaxies, IRAS 08572+3915. This galaxy has a deep 10 $\mu \rm m$ silicate absorption [2] and the strongest 3.4 $\mu \rm m$ interstellar absorption feature known [13, 7], nearly twice as strong as the one observed toward the Galactic center. The 3.4 $\mu \rm m$ feature is known to be associated with objects reddened by diffuse gas [1] and its strength in IRAS 08572+3915 tends to imply the existence of a long pathlength of molecular material along the line of sight to the nuclear infrared source.

2 Observations and results

In December 2000 a 3.82-3.98 μ m spectrum of IRAS 08572+3915 was obtained at UKIRT, using the facility spectrograph CGS4. The spectrum covered the wavelength range in which the redshifted 3.7 μ m lines of H_3^+ should appear. A portion of the spectrum is shown in Fig. 1 at a resolving power of $\sim 5,000$. Statistically significant absorption features are observed at the expected wave-

lengths of the two H_3^+ features, 3.8815 μm and 3.9317 μm , indicating that the molecular ion has been detected.

The 3.88 μ m doublet, which is blended but which also would be unresolved at the resolution used, appears to be roughly twice the strength of the singlet, indicating that the doublet has roughly equal contributions from its ortho and para components. The column density of ${\rm H_3^+}$ derived from the lines is about $5\times 10^{15}~{\rm cm^{-2}}$, roughly twice that found towards the Galactic center. This result is only mildly sensitive to the temperature, which cannot be determined accurately because of an insufficient signal-to-noise ratio and the low spectral resolution, but which appears to be 100 K or less. The FWHMs of the absorptions cannot be determined accurately, but are probably $150\pm50~{\rm km~s^{-1}}$, similar to that found toward the Galactic center.

3 Discussion and Conclusions

The velocity at which H_3^+ is seen in IRAS 08572+3915 is the systemic velocity; hence the associated gas is neither falling into nor being expelled from the presumed AGN [2]. Presumably the H_3^+ is mainly found in relatively quiescent interstellar medium far from the nucleus, as in the case of the Galactic center although in principle it could be located in a circumnuclear molecular disk. Currently it is uncertain whether the gas containing the detected H₃⁺ is in diffuse or dark clouds. However, the strong 3.4 μ m interstellar feature suggests that much of the gas must be diffuse. Assuming the canonical value of $\sim 1 \times 10^{-7}$ cm⁻³ for the density of H₃⁺ in diffuse gas [8, 4] the derived length of the column containing H_3^+ in IRAS 08572+3915 is ~ 10 kpc, which seems excessive. A similar unreasonably high result of several kpc was obtained for the Galactic center [4]. Using what is known by other means about the dimensions of diffuse clouds in our galaxy, such as Cygnus OB2 [4], an H₃⁺ density in diffuse clouds is derived that is roughly an order of magnitude higher than the canonical value, and for the Galactic center and IRAS 08572+3915 column lengths equivalently lower, and probably more sensible, are obtained.

An improved spectrum of H_3^+ in IRAS 08572+3915 together with observations and analysis of other molecular species are required to better pinpoint the location of the H_3^+ . New measurements of and improved confidence in the rate coefficient for dissociative recombination of H_3^+ on electrons, which determines the steady-state abundance of H_3^+ in diffuse clouds, also is needed. In the future, using ground-based 8–10 m class and larger telescopes along with the NGST, one can anticipate that spectroscopy of H_3^+ , in combination with measurements of dust, CO and other molecules, will be a standard technique for probing the interstellar gas in many distant galaxies.

Acknowledgements. UKIRT is operated by the Joint Astronomy Centre on behalf of the U.K. Particle Physics and Astronomy Research Council. I thank the staff of UKIRT for its support. I am grateful to B. J. McCall and T. Oka for helpful discussions.

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